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Lead block compression test for determining the brisance of selected explosives
Próba odkształcenia walca ołowianego do określania kruszności wybranych materiałów wybuchowych

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Abstract: *The Hess lead block compression test was used for the experimental determination of brisance of explosives. This method exploits the deformation of a lead block resulting from the detonation of explosive sample. The determination of brisance is based on the assumption that the compression of the lead cylinder is proportional to the brisance of an explosive sample. Results from this test may be expressed either directly via the deformation of the lead cylinder or as a compression factor. In this paper, experimental results of the brisance have been referenced to the brisance created by detonation of hexogen. Different explosives used in mining were tested, including bulk emulsion explosives, dynamite, ANFO and ammonium nitrate powdered explosives. Moreover, four reference high explosives were tested, which could be used as a reference explosives in some tests of working capacity.*

Streszczenie: *Próba odkształcenia walca ołowianego Hessa została wykorzystana do eksperymentalnego wyznaczenia kruszności materiałów wybuchowych. Metoda ta odpowiada deformacji walca ołowianego w wyniku detonacji próbki materiału wybuchowego. Wyznaczanie kruszności opiera się na założeniu, że wielkość odkształcenia walca ołowianego jest proporcjonalna do kruszności próbki materiału wybuchowego. Wyniki badań w tej metodzie można wyrazić zarówno jako rzeczywistą wartość odkształcenia walca ołowianego lub też jako współczynnik kompresji. W niniejszej pracy, eksperymentalne wyniki badań kruszności odniesiono do kruszności uzyskanej w wyniku detonacji próbki heksogenu. Analizie poddano różne górnicze materiały wybuchowe, w tym materiały wybuchowe emulsyjne luzem, dynamit, saletrole oraz materiały wybuchowe amonowo-saletrzane. Ponadto, przebadano cztery referencyjne materiały wybuchowe kruszące,* *które mogą być stosowane jako wzorcowe materiały wybuchowe w niektórych badaniach zdolności do wykonania pracy.*

Keywords: *explosives, brisance, Hess test*
Słowa kluczowe: *materiały wybuchowe, kruszność, próba Hessa*

1. Introduction

In order to characterize an explosive, a number of different physical parameters must be determined experimentally. Thus, different physical principles and experimental methods have been developed to date [1-3]. On the other hand, substantial progress has been observed in the field of computer simulation of the detonation process and interaction between explosives and rocks or other objects [4-5]. Results from measurements depend on both the instruments and the test procedures used. Moreover, procedures of explosive sample preparation affect the reliability of results. As is well known, some explosives cannot be tested using a specific technique or apparatus, which may be related, for example, to the critical diameter of the explosive. Therefore, certain methods and procedures have been standardized by the domestic and European standards. Some of the test techniques may only be used on a small scale, i.e. under laboratory conditions. Thus, some parameters cannot be determined under such conditions.

The ability of an explosive to create a strong shattering effect in its immediate vicinity is called brisance and is, therefore, its effectiveness at breaking rocks or other matter [6]. In recent years, this parameter has been the subject of research by the Authors of this paper, who used the Hess lead block compression test for determining brisance. Descriptions of this method may be found elsewhere [7, 8]. Based on the Authors' experience, the Hess method is a good alternative for determining the energy capacity of explosives compared to other more complicated, expensive and time-consuming methods. It appears to be well suited for testing different types of explosives but the greatest advantage is that it can be used directly at the firing site (mines), which is very beneficial, especially when testing bulk emulsions, because the samples may be collected directly from the mobile mixing-charging units.

In previous research [9], the brisance of selected emulsion explosives used in mining, both bulk and cartridged, was determined by the Hess method. Analysis confirmed that brisance is higher for packaged emulsions than for bulk emulsions. Results have shown that brisance increases with the increase of detonation velocity of explosives, as indicated by a very strong and almost perfect correlation between those parameters. In this paper, results of the brisance of selected explosives used in mining, determined via the Hess compression test, are presented. The analysis was supplemented with selected reference explosives.

2. Materials and methods

The objects of the research were selected mining explosives, i.e. bulk emulsion explosives (Emulgit RP-T2, Hydromite 100), dynamite (Ergodyn 31E), ANFO (SAL-Z), heavy-ANFO and powderous explosives (Amonit H3E and Metanit E7H). Both bulk emulsions were sensitized chemically prior to sample preparation. Four high explosives were also tested, which were used as reference explosives in some tests of working capacity. These were picric acid, plastic explosive, crystalline pentrite and hexogen. Selected parameters of the tested explosives, according to the technical data sheets, are presented in Tables 1 and 2.

Table 1. Selected parameters of the tested mining explosives

Explosive \ Parameter	Velocity of detonation [m/s]	Friction sensitivity [N]	Impact sensitivity [J]	Heat of detonation [kJ/kg]	Gas volume [dm^3/kg]	Minimal diameter [mm]	Density [g/cm^3]
Emulgit RP-T2	3200	318	34	3562	876	35	1.10 ±0.05
Hydromite 100	>4000	>360	≥20	2976	958	35	1.00 ±0.10
Ergodyn 31E	4500	>80	>2	5645	887	25	1.50 ±0.10
SAL-Z	2000	>360	>20	2503	997	50	0.70 ±0.10
Heavy-ANFO	2300	>360	>20	3129	1027	45	0.95
Amonit H3E	3000	353	5	4573	857	32	1.14 ±0.10
Metanit E7H	2100	288	20	2260	580	32	1.12 ±0.10

Emulgit RP-T2 is a bulk emulsion explosive mixed in situ using the mixing-charging unit by Maxam Polska Sp. z o.o. It is dedicated for blasting operations in underground mines and may be used in dry and wet holes. Hydromite 100 is the second site sensitized bulk emulsion explosive manufactured by Austin Powder Polska Sp. z o.o. This in turn is dedicated for blasting in open-pit mines and may be also used in dry and wet holes. Ergodyn 31E is a packaged nitroester-containing explosive intended for use in underground and open-pit mines. SAL-Z is an ammonium nitrate fuel oil (ANFO) produced from UltrAN 70 ammonium nitrate porous prills supplied by Yara Poland Sp. z o.o. and diesel oil from Orlen Refinery (ammonium nitrate/fuel oil ratio of 94:6). It is the most common explosive for civil use in the fields of mining and civil engineering. Heavy-ANFO in turn is a blend of ANFO and emulsion explosive. In this research, it was produced from SAL-Z ammonium nitrate fuel oil (75%) and Emulinit 9L bulk emulsion explosive (25%) delivered by Nitroerg S.A. Finally, Amonit H3E and Metanit E7H are powdered ammonium nitrate explosives manufactured by Nitroerg S.A. Both are intended for use in underground and open-pit mines, however, the latter is a permitted explosive for use in conditions of coal dust and/or methane explosion hazard.

Table 2. Selected parameters of the tested reference explosives

Explosive \ Parameter	Velocity of detonation [m/s]	Friction sensitivity [N]	Impact sensitivity [J]	Heat of detonation [kJ/kg]	Gas volume [dm^3/kg]	Critical diameter [mm]	Density [g/cm^3]
Picric acid	7350$^{a)}$	353	7.4	3437$^{a)}$	826$^{a)}$	4	0.81
Plastic explosive	7400	n/a	n/a	3780$^{a)}$	1090$^{a)}$	2	1.56
Crystalline pentrite	8400$^{a)}$	60	3	6322$^{a)}$	780$^{a)}$	6	1.11
Hexogen	8750$^{b)}$	120	7.5	6322$^{b)}$	903$^{b)}$	8	1.00

$^{a)}$ at 1.7 g/cm^3, $^{b)}$ at 1.76 g/cm^3

Picric acid and plastic explosive were supplied by Nitron (Poland). Picric acid is a high explosive which is mainly used as a reference explosive for the Trauzl lead block test. Plastic explosives in turn are mainly used in military applications. Crystalline pentrite was provided by Société Suisse des Explosifs. This high explosive is used in detonators and detonating cords. Hexogen was supplied by Nitrochem (Poland) and is used as a reference explosive in ballistic mortar tests. Picric acid, pentrite and hexogen are in bulk (powdered) form, while the plastic explosive is supplied as a plastic mass.

Research was conducted at the Central Mining Institute – National Research Institute's test site in Mikołów, Poland. As in the previous paper, the explosive samples were prepared in plastic cups. The required mass was taken and the samples were formed in the cups in the case of dynamite and plastic explosive. In turn,

when testing the ANFO, picric acid, pentrite, hexogen and powdered explosives, the relevant mass was taken and poured into the cups. Finally, components of both bulk emulsion explosives and heavy-ANFO were blended manually in larger cups and then poured into the test cups.
Brisance was determined using the Hess method, in accordance with the procedure described in the standard [10]. In this method, the difference in the lead block height before and after the test is calculated. Specifications concerning the equipment and instruments are outlined in the above standard. Dimensions of the blocks are 60 ±0.15 mm in height and 40 ±0.2 mm in diameter. Cylindrical steel crushers with a diameter of 41 ±0.2 mm and height of 10 ±0.2 mm were used. Casings for explosive samples and holders for detonators were made on a 3D printer (inner diameter of the cups was 40 and 65 mm in height). In each test, a lead block was placed on a steel base located on the ground, on which the steel crusher and 50 g explosive sample were placed. Due to the high brisance of the explosives listed in Table 2, with the exception of picric acid, it was decided to reduce the mass of explosive to 25 g. Samples were initiated using a standard 0.65 g PETN detonator. Experimental set and lead block after firing are presented in Figure 1.

Figure 1. View of the sample prior to firing (left) and lead block after the test (right)

Brisance is taken as the change in the height of the lead block caused by axial compression, which is calculated as the difference between the height of the lead block before test and the arithmetic mean of compression of the lead block height measured at four separate measuring points. According to the standard, brisance should be determined based on the results from three samples. The final value of brisance is the arithmetic mean from three sample firings. Results may be presented in millimetres or as the compression factor, which minimises the influence of lead compression changes depending on the degree of crushing.

3. Results

Brisance for each explosive was determined based on the firing of three samples and is presented graphically as the compression of the lead blocks values measured in accordance with the standard and as calculated compression factors. Results are presented in millimetres as one average value from three samples (Figures 1-4). Moreover, on each graph, the uncertainty in the mean value is also presented.
The greatest brisance of the tested mining explosives was observed for Emulgit RP-T2 (bulk emulsion),

amounting to 18.27 mm. Similar values were obtained for Hydromite 100 (bulk emulsion), Ergodyn 31E (dynamite) and Amonit H3E (powdered explosive). Particularly good results were achieved for Hydromite 100, which is intended for open-pits, where usually double the diameters are used. Also surprisingly good results were obtained for Amonit H3E, which is essentially weakly sensitive to thermal and mechanical stimuli. The lowest values, as expected, were observed for ANFO, heavy-ANFO and Metanit E7H. Dispersion in the compression of lead blocks for the tested explosives was relatively low.
As for the reference explosives, the greatest value was observed for plastic explosive. The measured brisance was 22.25 mm, which is almost 4 mm higher than that of Emulgit RP-T2. However, it should be emphasized that the mass of the sample was two times smaller. Brisance of crystalline pentrite was 19.63 mm, which is also a greater value than the greatest value obtained for mining explosives. The lowest brisance was measured for hexogen, nevertheless this result is close to results obtained for the strongest mining explosives. Similar conclusions may be drawn from the graph of compression factors for each of the tested explosives.

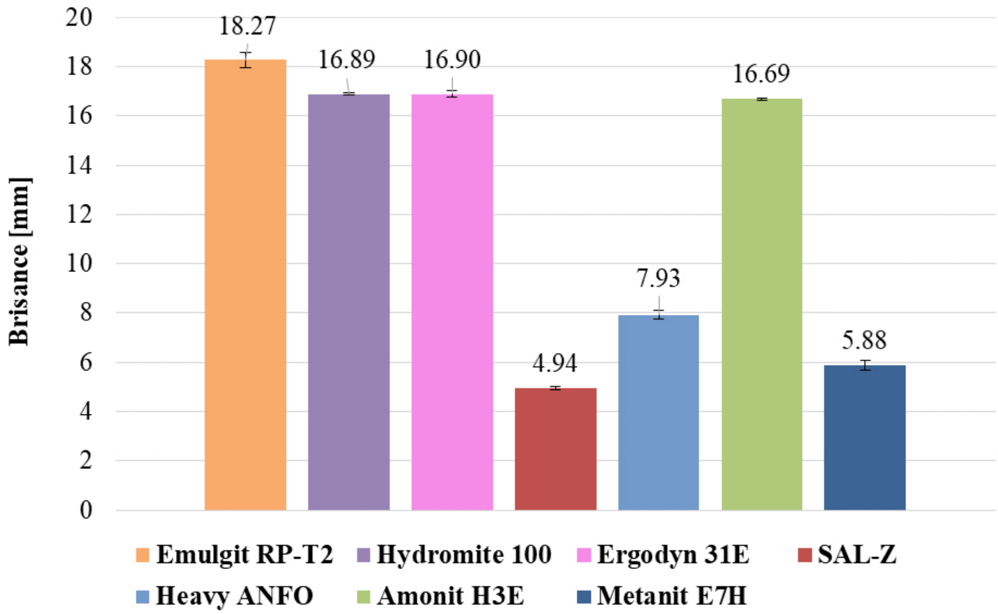

Figure 1. Results of brisance for tested mining explosives

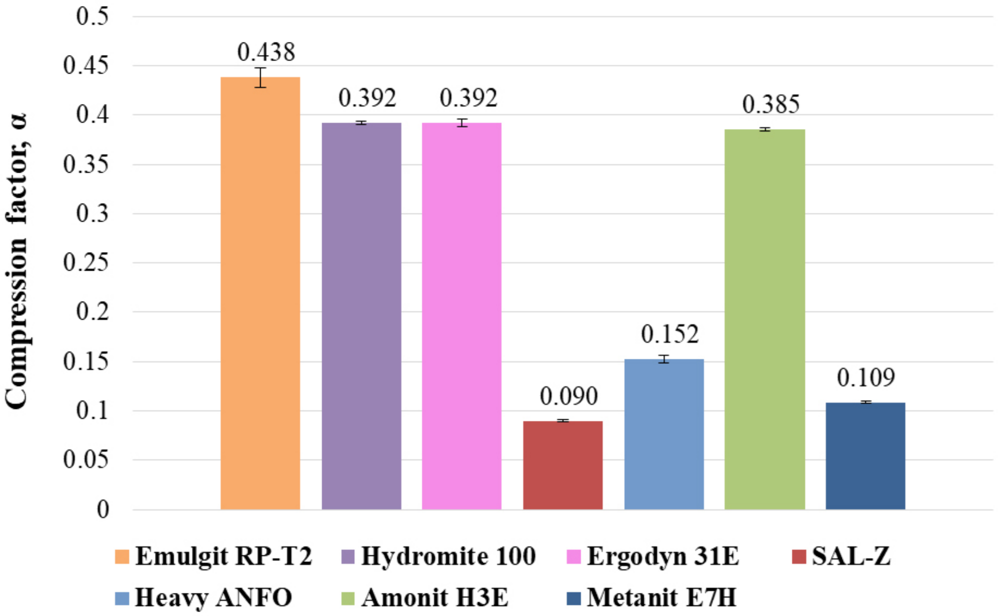

Figure 2. Compression factors for tested mining explosives

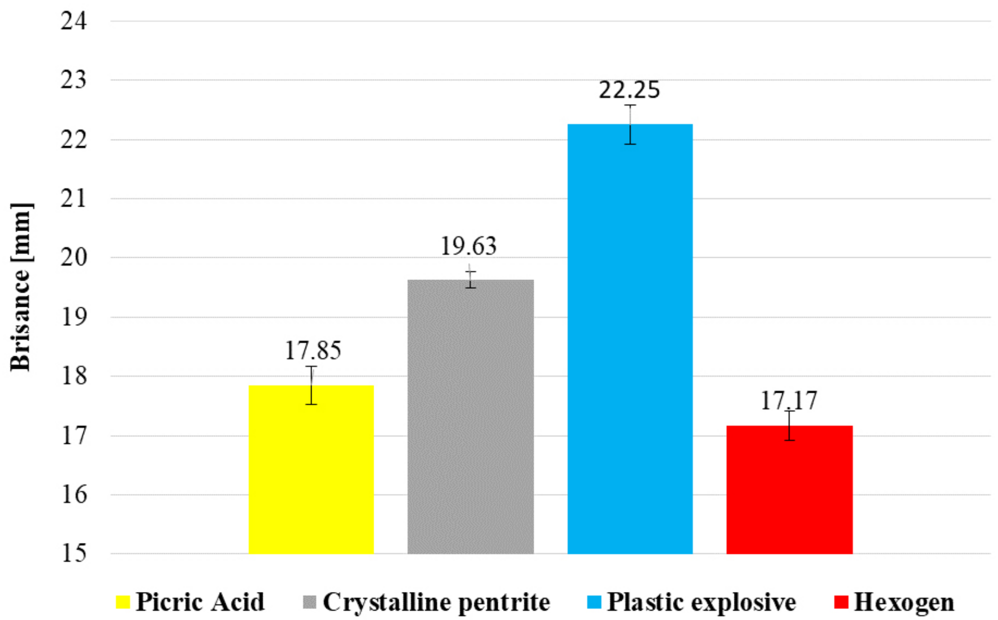

Figure 3. Results of brisance for tested reference explosives

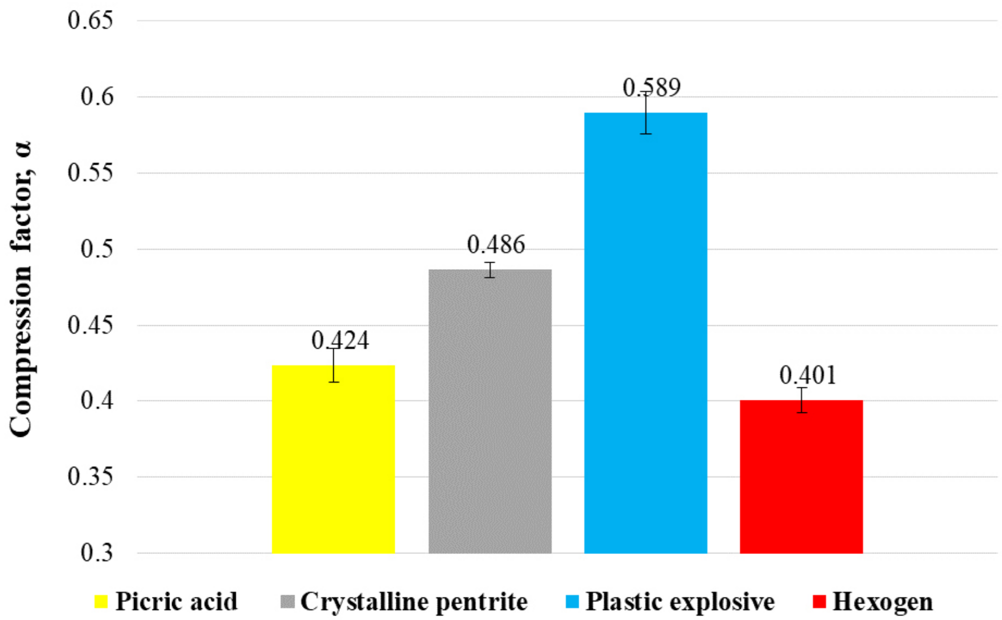

Figure 4. Compression factors for tested reference explosives

4. Discussion

Results have shown that the Hess method cannot be used for determining brisance of some explosives. In the case of explosives which have greater critical diameters, such as ANFO or heavy-ANFO, results are much lower than in the case of other explosives. The sample diameter of 40 mm is too small for testing of this type of explosives. Thus, this method should be modified in such a way as to increase the diameter.

Brisance of Metanit E7H reached 5.88 mm despite the relatively small critical diameter compared to ANFO and heavy-ANFO. The low value is associated with the low detonation velocity of this explosive which is only 2100 m/s but also with the higher salt content in the explosive (up to 40 wt.%). Due to the very low deformation of the lead cylinder, it can be concluded that the Hess method is not suitable for testing explosives with a low detonation velocity and high salt content, which significantly reduces the heat of detonation.

Brisance of the remaining tested mining explosives ranged from 16.69 mm for Amonit H3E to 18.27 mm for Emulgit RP-T2. Results are quite similar to each other. However, the deformations did not cause tearing of the lead cylinder. Therefore, it can be concluded that testing of dynamite, emulsion and ammonium nitrate explosives using the Hess method, gives reliable results.

The results from the reference explosives reveal that brisance for these is much higher than for explosives used in mining. Based on the analysis, it was found that the plastic explosive should not be used as a reference explosive, due to the high density and very large deformation of the lead cylinder, despite the reduction of the sample mass to 25 g. Deformation was not axial, so determination of brisance can be affected by an error. The brisance of plastic explosive is very high, amounting to 22.25 mm. Partial rupture of the lead cylinder was noted, which may have had a strong influence on the result (Figure 5).

Figure 5. Lead blocks after the tests: ANFO (left), Hydromite 100 (middle) and plastic explosive (right)

Pentrite was also characterized by a high brisance of 19.63 mm. It should be noted that this value is also too high compared to the explosives for civil use. Thus, it was found that the optimal explosives used as a reference are hexogen and picric acid, for which the brisance was 17.17 and 17.85 mm, respectively. They were lower than obtained for Emulgit RP-T2, which was 18.27 mm. Picric acid seems to be a better reference due to the sample mass which was 50 g compared to hexogen (25 g). The small mass of the test sample causes a very short run-up between the detonator and the steel crusher. On the other hand, picric acid is difficult to access and disruptive to elaborate into the cups. In the tests of crystalline pentrite, plastic explosive and hexogen, in which 25 g explosive sample was used, the distance between the detonator and crusher was very small, which meant that the length of the sample was twice as short as its diameter. Due to different densities of explosives, the total length of the sample varied from 13.1 to 57.1 mm, then the length of low density samples was more than four times longer than for high density ones (Figure 6).

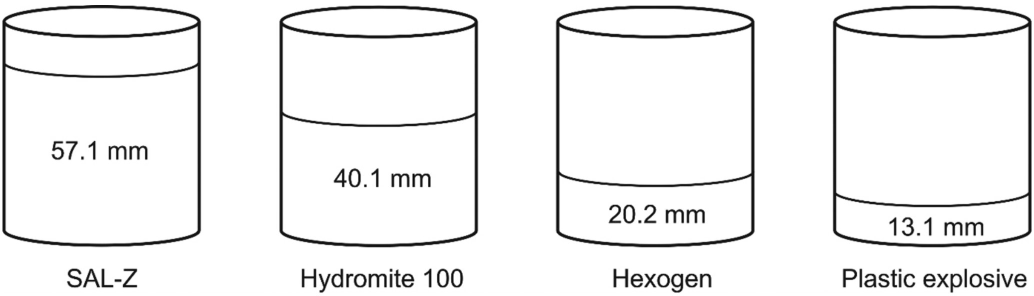

Figure 6. Differences in the lengths of explosives samples for selected explosives

Finally, the relationship between brisance and detonation velocity specified in Tables 1 and 2 was determined (only 50 g samples were considered). The linear correlation between those parameters is medium and approximately 70% of the data fitted to the regression model (Figure 7). Results differ from those presented in the previous paper [9], in which the coefficient of determination for correlation of brisance and detonation velocity for selected emulsion explosives was very strong and almost perfect.

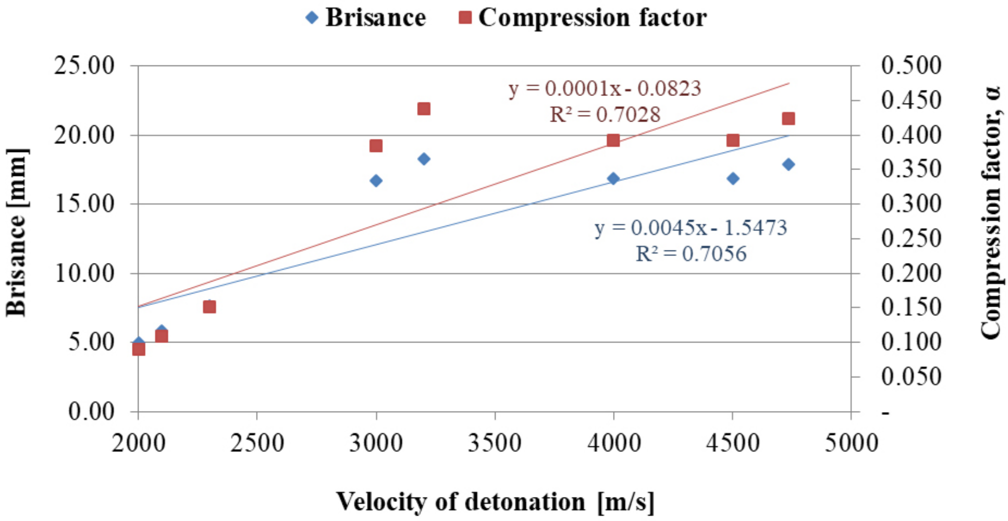

Figure 7. The relation between brisance, compression factor and detonation velocity

Experimental results of the lead block compression tests using the Hess method have proved that this method may be used for the testing of both civil and military high explosives. The results of the tests showed that, of the four tested reference explosives, hexogen gives the greatest results.

5. Conclusions

- Experimental results from the lead block compression tests using the Hess method have proved that this approach may be certainly used for determining the brisance of selected explosives, both civil and military high explosives. The results show that, generally, brisance increases with the increase in the detonation velocity. However, it is strictly related to the type of explosive and its density.
- From the point of view of sample preparation, forming the samples from powdered granular explosives seemed to be the easiest. Testing ANFO and heavy-ANFO is more likely to failure, since the sample diameter is very close to the critical diameter of those explosives and the risk of a misfire is relatively high.
- Even though the plastic explosive samples were two times smaller than the other tested explosives, very large deformations of the lead cylinders were observed. Moreover, too high differences at individual measuring points were noticed. Thus, plastic explosive should not be considered as a reference explosive.
- Analysis confirmed that among the reference explosives, a 25 g sample of hexogen or a 50 g sample of picric acid seem to be the most appropriate. However, due to the problems with the availability of the latter and difficulties with sample preparation, it is suggested that hexogen be used as a reference explosive in the Hess lead block compression tests.
- The Hess method is a good alternative for determining the energy capacity of different type of explosives compared to other methods. Testing procedure is simple and gives reproducible results.

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